

Seismic Isolation Retrofitting Experience in Armenia and New Structural Concept for an Existing 8-Story Reinforced Concrete Hospital Building to be Retrofitted by Base Isolation

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Abstract

Four remarkable projects on retrofitting by base isolation: (i) of an existing stone apartment building that was made in the city of Vanadzor (Armenia) without resettlements of the occupants; (ii) of about 100 years old stone bank built in the city of Irkutsk (Russia); (iii) of a 60 years old non-engineered stone school built in the city of Vanadzor (Armenia); and (iv) of about 180 years old historical building of the Iasi City Hall in the city of Iasi (Romania) which is briefly described in the paper to demonstrate accumulated in Armenia experience of retrofitting by seismic isolation. Based on this further developments have taken place and the given paper is mainly focused on retrofitting design of the existing 8-story reinforced concrete hospital building. The paper describes the new structural concept of retrofitting by base isolation developed in 2013 and the results of analysis of this building in accordance with the provisions of Armenian Seismic Code and also time history analysis. The created solution is proposed for the first time and envisages gradual cutting the structural elements and placing simultaneously the seismic isolators. Operations are designed to be performed in 11 stages for the columns and 12 stages for the shear walls.

Keywords

Seismic Isolation; Retrofitting; New Structural Concept; Existing Building; Laminated Rubber-steel Bearings; Response Analysis; Building Code; Time Histories

Introduction

The retrofitting technique using base isolation has great potential for rehabilitation of ordinary civil structures such as apartment blocks and critical facilities such as schools, hospitals. It is well known that in this case the first dynamic mode of the isolated building involves deformation only in the isolation system, the building above being to all intents and purposes rigid. The higher modes do not participate in

the motion so that the high energy in the ground motion at these higher frequencies cannot be transmitted into the building.

Several remarkable projects on retrofitting by base isolation were developed and implemented using technologies created by the author of this paper. One of them is retrofitting of a 5-story stone apartment building. The operation was made without resettlements of the occupants. World practice provides no similar precedent in retrofitting of apartment buildings. The project was implemented in Armenia in 1996. Then by the end of nineties, another project on retrofitting of about 100 years old 3-story stone bank building was implemented in the city of Irkutsk, Russia with increasing of the number of stories up to 4. For retrofitting of this building by base isolation the author of this paper provided to Russian and Chinese colleagues all the needed drawings, photos, video film related to the retrofitting works carried out in Armenia. The other project is retrofitting of the 60 years old non-engineered 3-story stone school building which has historical meaning as well as a great architectural value. Unique operations were carried out in order to install the isolation system within the basement of this building and to preserve its architectural appearance. The project was implemented in Armenia in 2002.

Experience accumulated in Armenia in retrofitting of existing buildings including those of historical and architectural value created a good basis for participation in the international competition announced by the Government of Romania for development of the design on retrofitting of about 180 years old 3-story historical building of the Iasi City

Hall by base isolation. The structural concept, including the new approach on installation of seismic isolation rubber bearings was developed and the design of retrofitting was accomplished in cooperation with the Romanian company MIHUL S.R.L. The design was finally approved by the Technical Committee for Seismic Risk Reduction (a body especially created by the Government of Romania) on June 1, 2009. All the above mentioned projects are briefly described in the paper.

In 2013 a new structural concept for an existing 8-story R/C Haematology Centre building to be retrofitted by base isolation was suggested and developed. The seismic isolation of the building in this project is planned to implement at the basement level. All together 117 seismic isolation laminated rubber-steel bearings (SILRBs) were used with aggregate horizontal stiffness of 94770 kN/m. Their sizes and physical/mechanical parameters together with the detailed description of all phases for cutting the columns and shear walls and placing the seismic isolators are given in the paper. Results of analysis of this retrofitted building by the Armenian Seismic Code and the time histories are also given and discussed.

Seismic Isolation Retrofitting Experience in Armenia

Retrofitting of an Existing 5-Story Stone Apartment Building

The first retrofit of 1A-450 series stone apartment building with load bearing walls (FIG. 1) has been carried out in Armenia in the city of Vanadzor in 1995-1996, financed by the World Bank and co-financed by UNIDO (Melkumyan, 2002, 2011). The high damping rubber bearings (HDRB) for this retrofit project were designed with significant help and support of the UK based Malaysian Rubber Producers' Research Association (MRPRA). 60 HDRBs were used in the project, of which 28 bearings have been manufactured by MRPRA and 32 in Malaysia by Min Rubber Products Sdn. Bhd. and Sime Engineering Rubber Products Sdn. Bhd (Fuller et al., 2000). The structural concept aims at retrofitting an existing building with seismic isolators using a simple and innovative working technology developed by the author of this paper (Patent of the Republic of Armenia #579, 1996). This is a unique and pioneering seismic isolation project implemented for an existing 5-story stone building without re-settlement of the dwellers. There

has been no similar precedent in the world practice of retrofitting apartment buildings. The isolators in this building are located by upper and lower recesses provided by annular steel rings bolted to outer steel plates which are connected to the reinforcement in the upper continuous and lower foundation beams; the isolators are not bolted to the structure (FIG. 2).



FIG. 1. GENERAL VIEW OF THE EXISTING 5-STORY STONE APARTMENT BUILDING RETROFITTED BY BASE ISOLATION AND FRAGMENTS OF ITS ISOLATION SYSTEM

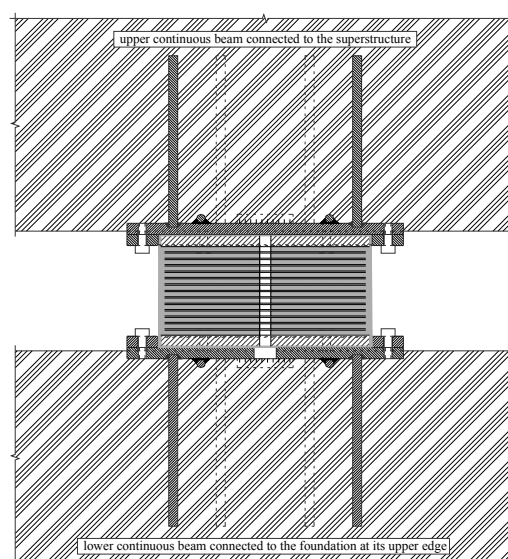


FIG. 2. LOCATION OF HDRB BY UPPER AND LOWER RECESSES PROVIDED BY ANNULAR STEEL RINGS BOLTED TO THE OUTER STEEL PLATES CONNECTED TO REINFORCEMENT IN THE UPPER CONTINUOUS AND LOWER FOUNDATION BEAMS

This method of connection helps to minimize the cost of the isolators themselves and simplifies their installation on site. The side, top and bottom rubber cover layers ensure that the steel plates are protected from corrosion. In the existing building under consideration the bearings were not to be located in an enclosed, heated basement, but would be exposed to the outside environment. The severe winter weather at the site meant that particular attention had to be paid to the low temperature crystallization resistance of the rubber compound. Thus, a rubber compound suited to

sites with severe winter temperatures has been developed. The sixth cycle force-displacement loops are given in FIG. 3 for the bearings and their stiffness is seen to decrease with increasing displacement. The increased stiffness at small displacements reduces the movement of the building under wind loading without the need for additional wind restrain devices. Dynamic tests on the bearings showed the performance of the design to be satisfactory. The bearing test results confirmed that their stiffness and damping are predicted reasonably well from the design equations and rubber properties, as measured on small tests pieces. The bearings were also tested quasistatically in shear under the vertical load of 820 kN up to the maximum horizontal displacement of 195 mm (FIG. 4). The corresponding force-deflection plot shows a slight stiffening at large deflection; there is no sign of an approach to the displacement capacity of the isolator (Fuller et al., 2000).

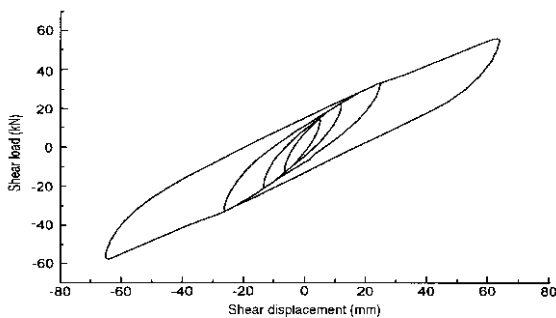


FIG. 3. SHEAR FORCE-DEFLECTION LOOPS FOR HDRBS. NOMINAL VERTICAL LOAD 500 KN

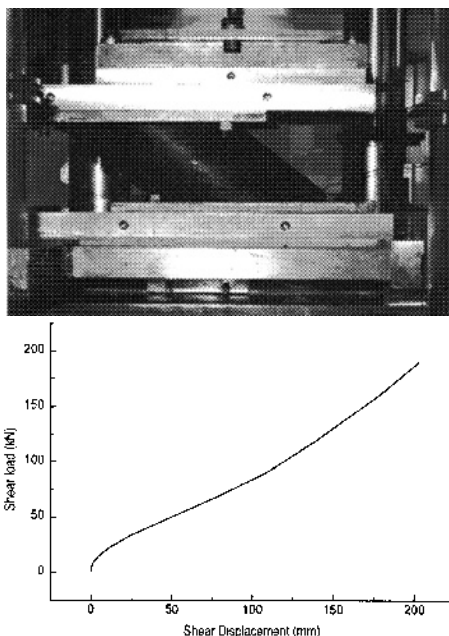


FIG. 4. HDRB TESTED UNDER COMBINED SHEAR AND COMPRESSION AND QUASISTATIC SHEAR FORCE-SHEAR DISPLACEMENT CURVE UNDER CONSTANT VERTICAL LOAD OF 820 KN

Retrofitting of an Existing 4-Story Stone Bank Building

This section describes in brief the project initiated by Prof. Eisenberg and Dr. Smirnov that was implemented in the city of Irkutsk, Russia. The main points of their paper on this topic (Smirnov, et al., 2000) presented at the 12th WCEE are given below. It was emphasized in the paper that for retrofitting the existing bank building by base isolation they have used the method developed by the author of this paper in (Melkumyan, 1997), who also provided them with all the needed drawings, photos, video film related to the retrofitting works carried out in Armenia. Prof. Eisenberg and Dr. Smirnov had also visited the retrofitted apartment building in Vanadzor and familiarized themselves with the details of creation of the base isolation system under the existing apartment building. The existing bank building in the city of Irkutsk did not meet the current Russian Seismic Building Code (SBC) requirements in respect of its dimensional and structural layout and seismic strengthening of the building were needed (Smirnov, et al., 2000). The retrofit targets included: ensuring earthquake resistance of the building to satisfy SBC requirements, re-planning premises and adding one or two upper stories to the superstructure as to convert the whole structure into a four-storied building (FIG. 5).



FIG. 5. GENERAL VIEW OF THE IRKUTSK (RUSSIA) BANK BUILDING RETROFITTED BY BASE ISOLATION

The external brick walls, internal transverse walls, and two longitudinal rows of brick columns comprised the load-bearing structures of the building. The retrofitting project included the following stages: the 3rd floor was to be added to the two-storied parts of the building, and the fourth garret story arranged above the whole building; all existing wooden floors were to be replaced by monolithic ones; the garret story was to be constructed by metallic structures with

efficient fire-resistant warmer; the foundations for columns in the central part were to be deepened down to the hard (firm) soil. A basement was to be arranged in the central part.

According to the reconstruction project, the seismic isolation bearings were to be arranged under all walls, piles, and columns at the level of the basement floor. The foundations were to be additionally strengthened in accordance with seismic loads values. A decision was made to install seismic lead rubber bearings at the mid level of the basement floor to provide effective seismic isolation of the existing walls and building columns. The total number of seismic bearings (produced by Vibro-Tech Industrial and Development Co. Ltd. Shantou, China) to be installed was 108. All bearings had the same dimensions: diameter – 510 mm, height – 216 mm.

The retrofitting method developed for the building in Vanadzor was implemented in this case in the following sequence for brick and reinforced concrete piles:

- pile surface is prepared for concreting (FIG. 6a);
- timbering and reinforcement cage are installed, then concrete is poured into timbering. Reinforced concrete casing thickness is 100 mm (FIG. 6b);
- after concrete reaches design strength, the middle part of piles is cut through to make openings. The vertical load of the building is transferred at this time to the concrete casings (FIG. 6c);
- the timbering, lower metallic frame are installed, and the bearing part for an isolator is concreted. The seismic bearing is placed. Timbering, upper metallic frame are installed, and the part above the bearing is concreted (FIG. 6d);
- after all the bearings are mounted in their places, the concrete casing is cut in proper areas, and the vertical load is transferred on seismic bearings (FIG. 6e), and for exterior stone block walls:
- earth is removed from the external and internal sides of the basement floor wall and upper part of the continuous footing (FIG. 6f);
- the timbering for reinforced concrete beams is installed on the external and internal side at the level of foundation top and basement floor wall bottom. Metallic frames and embedded parts for beam bracing are installed after concrete reaches its design strength. The upper beams are concreted in a way that leaves open recesses in the areas where seismic bearings are

to be located (FIG. 6g).

-the lower beams are concreted simultaneously with the piles for seismic bearings (FIG. 6h);

-the bearings are installed on reinforced concrete piles. Embedded parts are placed on the bearing, and the upper recess above the bearing is concreted (FIG. 6i);

-finally, the remaining parts of the basement floor wall between the isolators are dismantled, and the vertical load from the walls is transferred on the lead rubber bearings (FIG. 6j).

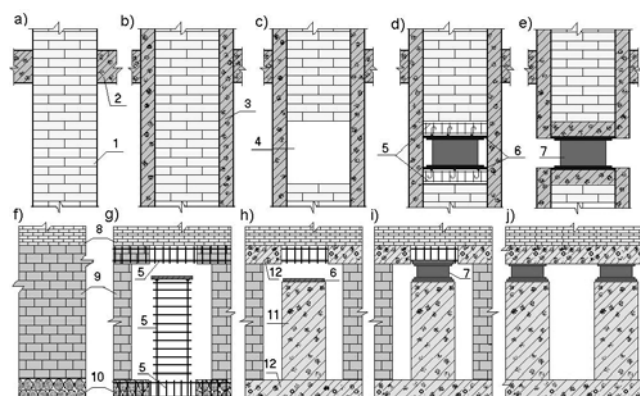


FIG. 6. PROCEDURE OF INSTALLATION OF SEISMIC ISOLATORS

- 1 - brick masonry column; 2 - reinforced concrete beam; 3 - external reinforced concrete cage; 4 - cut-through portion of column; 5 - steel bar; 6 - steel plate; 7 - seismic isolator; 8 - brick masonry wall of the first story; 9 - block masonry wall of the basement story; 10 - stone and concrete strip foundation; 11 - reinforced concrete pile; 12 - upper and lower portion of beams

As it is stated in (Smirnov, et al., 2000), retrofitting the bank building by base isolation enabled to preserve the building's exterior appearance and to avoid marring its architectural features. Also, thanks to the seismic isolation there was no need to carry out overall strengthening of the superstructure. Only minimum structural measures were taken here to meet the requirements of the SBC. The retrofitting went on without interrupting operation of the bank and its cost proved to be much lower than the cost of traditional strengthening technologies. Based on the performed calculations, analysis and design, the authors of this project confirmed that the reliability of the bank building with seismic isolation was considerably higher than with conventional strengthening.

Retrofitting of an Existing 3-Story Stone School Building

The other retrofit has been carried out in Armenia in 2001-2002. This was the school #4 in the city of Vanadzor and this building not only has a historical

meaning for the city, but also a great architectural value (FIG. 7). With this in mind, the financing organization – Caritas Switzerland – has agreed with the proposal of the author of this paper to retrofit the building by base isolation. The unique operations were carried out to install seismic isolation bearings in this building (Melkumyan, et al., 2003). The school is a 3-story, over 60 years old built with thick bearing walls made of tuff stones. Actually, this building is a non-engineered structure with wooden floors in some of its parts. The design for retrofitting of this school together with implementation of base isolation was set to replace the wooden floors by the R/C slabs. These operations were performed simultaneously with installation of the base isolation system at the level of the school basement. Forty-one medium damping rubber bearings for retrofitting of this building were manufactured in Armenia by the Yerevan Factory of Rubber Technical Articles.



FIG. 7. GENERAL VIEW OF THE 3-STORY SCHOOL BUILDING RETROFITTED BY BASE ISOLATION



FIG. 8. TESTING OF SEISMIC ISOLATION BEARINGS FOR RETROFITTING OF THE EXISTING SCHOOL BUILDING

In order to test seismic isolation rubber bearings, special testing facilities were designed and manufactured (Melkumyan & Hakobyan, 2003, 2005). The loading system was set to test simultaneously two rubber bearings under horizontal and vertical loadings and could produce up to 1000 kN of force on the bearings in both directions. It consisted of two side columns, upper and lower beams, a steel plate

movable in the horizontal direction and a horizontally immovable upper plate. The bearings were compressed by vertical force, through a hydraulic jack, which was located in the frame and the axis of which coincided with the longitudinal axis of the frame and bearings. The actuator was positioned in such way that its longitudinal axis was in one horizontal plane with the internal movable plate (FIG. 8).

The thickness of bearing walls in this building varies from 600 mm to 1150 mm in the basement and from 600 mm to 700 mm in the floors above the ground. There is a school sports hall located between the axes "A"-"C" and "5"-"6". The height of the sports hall is equal to the height of the basement plus the height of the first floor. This, along with the U-shape plan, causes significant asymmetry to the building relative to the longitudinal axis "D". Actually the plan of the building in the limits of the basement and the first floor is almost rectangular (FIG. 9a), while the plans of the second and third floors are U-shaped (FIG. 9b).

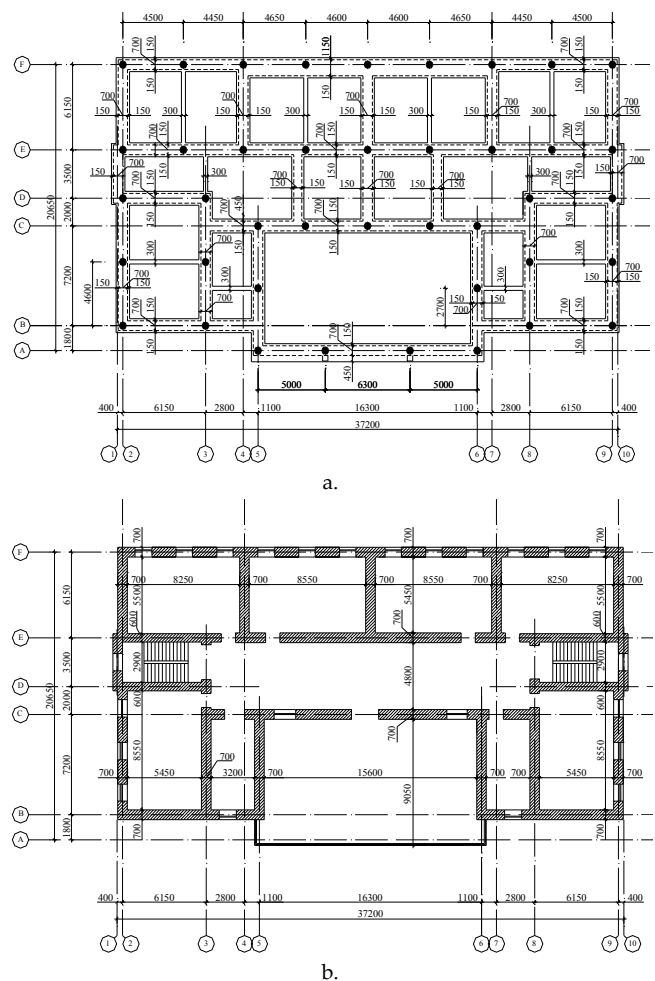


FIG. 9. THE PLANS OF THE BASEMENT WITH LOCATION OF SEISMIC ISOLATORS ON THE LOWER CONTINUOUS BEAMS (A), AND SECOND AND THIRD FLOORS (B) OF THE 3-STORY SCHOOL BUILDING RETROFITTED BY BASE ISOLATION

The school building had survived the 1988 Spitak Earthquake and fortunately the effect of this earthquake on the building was not very damaging. The building suffered inclined cracks mainly in the walls located around the staircases. Therefore, it was also decided to strengthen parts of the existing damaged walls by cement injection and/or by reinforced concrete jackets. These operations were also performed simultaneously with installation of the base isolation system.

Base Isolation Retrofitting Design of the Cultural Heritage Building of Iasi City Hall

Experience accumulated in Armenia in retrofitting of existing buildings including those of historical and architectural value created a good basis for participation in the international competition announced by the Government of Romania for development of the design on retrofitting of about 180 years old 3-story historical building of the Iasi City Hall (Iasi County) by base isolation. The retrofitting design was to be implemented within the framework of the Romania Hazard Risk Mitigation and Emergency Preparedness Project financed by the World Bank. The design was accomplished under the leadership of the author of this paper in cooperation with the Romanian company MIHUL S.R.L. and was finally approved by the Technical Committee for Seismic Risk Reduction (a body especially created by the Government of Romania) on June 1, 2009.



FIG. 10. VIEW OF THE IASI CITY HALL BUILDING

As described in (Miyamoto & Gilani, 2007), the Iasi City Hall building (FIG. 10) was originally constructed in 1810's in neo-classical Viennese style, and its façade was decorated with marble statues of mythological characters. It was modified in 1860's and turned into City Hall in 1891. It is considered a cultural heritage building and used to be the Romanian Royal Family

residence. However, some other sources, as indicated in the Request for Proposal (RFP) prepared by the Management Unit of the mentioned Project, who asserted that the building was originally constructed in 1832 as the Roznovanu Palace, with a partial basement, ground floor, first floor and partial attic space. The rooms were painted by Ludovic Stavschi and the Chapel by Ioan Balomir. The Palace has large aisles, high-ceilinged ball rooms and marble floors. The Palace underwent a major remodeling in 1985, creating the mansard, roof structures and entrance staircase that are visible today.

Taking into account that the Iasi City Hall building has historical and architectural value, evidently the conventional (traditional) methods of strengthening (reinforced concrete jacketing, construction of additional shear walls and frames, etc.) are not applicable to this building. There are known cases, when the application of conventional methods of strengthening to similar type of buildings has brought to significant disfiguration of their façades and interiors. The above upholds that the City Hall should be retrofitted using innovative seismic (base) isolation technologies. As it is mentioned in the Introduction in this case, the first dynamic mode of the isolated building involves deformation only in the isolation system, the building above being to all intents and purposes rigid (Naeim & Kelly, 1999). The key objective of the given work was to develop a structural concept and design for retrofitting the Iasi City Hall building by base isolation, which would ensure cost-effectiveness of the construction works, high reliability of the structure and preservation of the historical and architectural value of the building.

Base isolation method for this existing building with bearing walls that involved placing seismic isolators at the level of basement solved the problem through the same innovative technology as was mentioned above for the apartment, bank and school buildings (Patent of the Republic of Armenia #579). Obviously, before creation of the isolation system, the basement walls must be thoroughly cleaned and washed from the remainders of soil and then adequately strengthened. The proposed structural solution provides for jacketing of the natural stone walls of the foundations and basement. The new approach on installation of seismic isolators by clusters described in (Melkumyan & Hovhannisyan, 2006, Melkumyan, 2013) and successfully implemented in many buildings in Armenia was also proposed for retrofitting the Iasi City Hall building (FIG. 11). It was also proposed to

lay a 150 mm thick reinforced concrete slab immediately above the seismic isolation plane to cover the basement (FIG. 12). This approach would significantly increase the reliability of the whole structure (i.e. the building itself plus the isolation system), led to an increased rigidity of the superstructure (the part of the building above the isolation plane) and would result in a more uniform distribution of seismic forces on isolators.

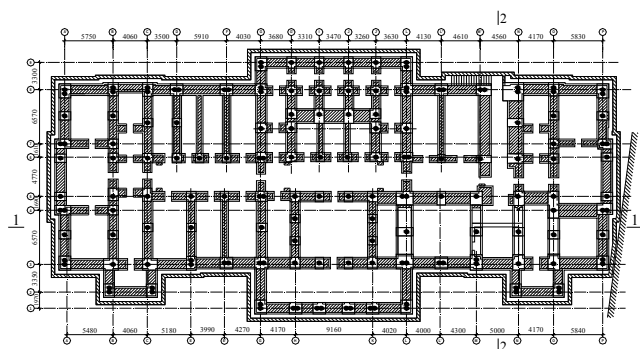


FIG. 11. PLAN OF LOCATION OF SEISMIC ISOLATORS ON THE LEVEL OF THE BASEMENT HIGHLIGHTING THE LOWER PEDESTALS UNDER THE ISOLATORS AND THE LOWER CONTINUOUS BEAMS ALONG THE WHOLE PERIMETER OF THE BEARING WALLS

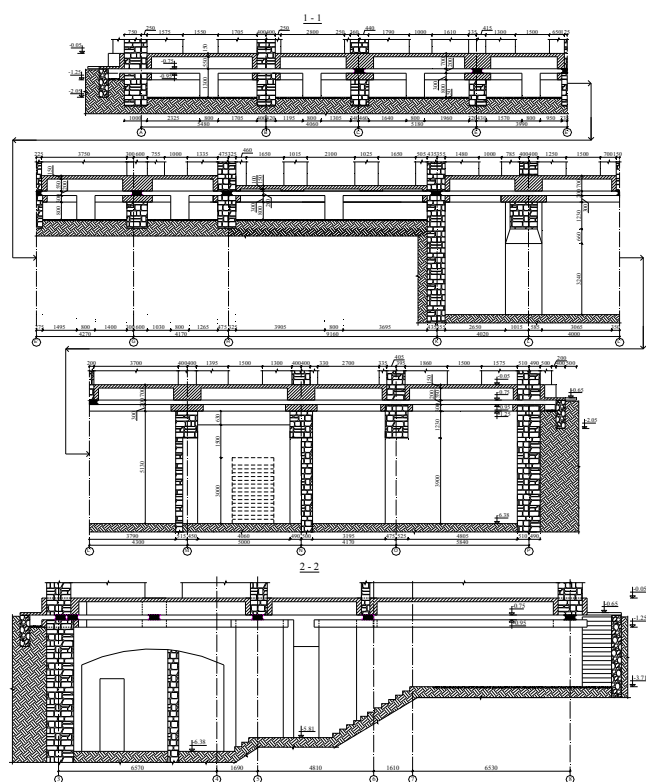


FIG. 12. LONGITUDINAL (1-1) AND TRANSVERSE (2-2)
VERTICAL ELEVATIONS OF THE BASEMENT AND ITS
ISOLATION SYSTEM

Earthquake response analysis of the building was carried out by SAP2000 non-linear program in two versions considering the linear and nonlinear behavior

of isolators with the application of the following input parameters based on the historical tests data of seismic isolation rubber bearings (Melkumyan & Hakobyan, 2005): yield strength – 56 kN; yield displacement – 19 mm; damping factor – 15%. The non-linearity was considered only for seismic isolators because for cases like Iasi City Hall building there was no need to apply non-linearity to the superstructure. For the linear model, the isolators were assigned effective stiffness of 0.81 kN/mm. For non-linear model, the isolators have initial stiffness of 3 kN/mm and post yield stiffness of 0.81 kN/mm. For the analysis, 9 accelerograms (all recorded in Romania) were selected and all records were scaled to acceleration of 0.28g.

The following results of calculations were obtained: periods of vibrations in X and Y directions are both equal to 2.13 sec; floor accelerations along the height of superstructure in both directions are the same, equal to 0.085g in average, meaning that thanks to application of base isolation, the input PGA of 0.28g decreases by about 3.3 times; in none of the isolators, the vertical force exceeds 1500 kN; superstructure is moving in horizontal direction as an absolutely rigid body without any overturning and together with the above results, this underlines the high effectiveness of the created base isolation system. Also it should be mentioned that for small deformations corresponding to the wind impact, the initial stiffness of rubber bearings is much higher than their effective stiffness and, thus, the ability of the system to provide an intrinsic restraint against wind loading is confirmed. All structural elements above and below the isolation interface are working only in the elastic stage. In comparison with the linear analysis, non-linear analysis shows an increase (27%) of average displacement of isolation system and a decrease (35%) of average floor accelerations above it. It can be noticed that in base isolated building, the maximum average story drift of superstructure is equal to 1.67 mm. The stress-strain states check shows that retrofitting of this building by base isolation makes it unnecessary to strengthen the superstructure (Melkumyan, 2011, Melkumyan, et al., 2011).

New Structural Concept for an Existing 8-Story Reinforced Concrete Hospital Building to be Retrofitted by Base Isolation

General Information on the Structural System of the Existing Building

The project of seismic isolation and reconstruction of

the 8-story (plus a basement) hospital building (Hematology Centre) located in Yerevan (FIG. 13a,b), was implemented at the order of the Healthcare Project Implementation Unit and financed by the World Bank. The project is based on a seismic isolation method, the structural concept of which has been developed by the author of this paper. During the development of the project design, principally new structural approaches have been proposed for seismic isolation of the building's reinforced concrete (R/C) bearing frame. The existing building has rectangular plan with dimensions of 36.4×24.4 m, six spans of 6 m each in longitudinal direction and four spans of 6 m each in transverse direction. The bearing (moment resisting) frames with strong beams of cross section 400×520(h) mm are located in transverse direction, while in longitudinal direction, there are frames with the interior weak beams of cross section 1200×250(h) mm and exterior weak beams of cross section 800×250(h) mm and with shear walls of the thickness equal to 140 mm. Cross section of all the columns is equal to 400×400 mm. The height of floors from 1-st to 7-th is equal to 3.3 m, of 8-th (technical) floor – 2.5 m.



a.



b.

FIG. 13. VIEW OF THE HEMATOLOGY CENTRE EXISTING BUILDING BEFORE (A) AND ITS DESIGN VIEW AFTER RENOVATION AND RETROFITTING BY BASE ISOLATION (B)

The Set Objectives and Parameters of the Used Seismic Isolation Laminated Rubber-Steel Bearings

The seismic isolation of the building in this project is

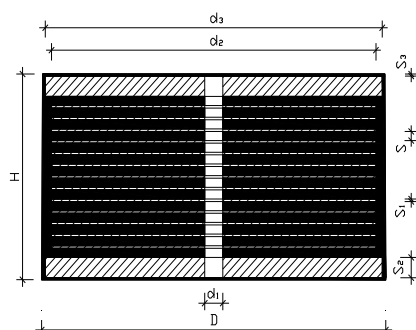
planned to be implemented at the basement level. The main objective is to implement the proposed structural solution for seismic isolation of the existing building in parallel with its full renovation. This is one of the advantages of retrofitting by base isolation when superstructure can be renovated immediately with the implementation of the works on retrofitting. Obviously, this will significantly shorten the whole construction process. Such an approach becomes possible as due to application of base isolation to this existing building, there is no need to strengthen the structural elements of the superstructure. Along with providing the high reliability to the building, seismic isolation also allows considerable savings in construction cost. The experience in seismic isolation of existing buildings in Armenia has shown that compared to other methods for improving the earthquake resistance of the buildings, seismic isolation is several times less expensive (Melkumyan, 2013). At the same time, an objective is set to determine the dynamic characteristics of the building after completing the seismic isolation and reconstruction works, and to compare displacements during micro-oscillations for the superstructure and part of the building below the seismic isolation plane level. It is decided to thoroughly follow/record all activities in all phases of seismic isolation system construction by photo and video cameras, to archive the obtained materials, as well as to place seismic sensors with identical specifications at all levels of the building, including the basement floor, in order to record accelerations, displacements and dynamic characteristics during seismic impacts in mutually perpendicular directions.

Seismic isolation laminated rubber-steel bearings (SILRSB) of same type and sizes were used to make the seismic isolation system. Total 117 SILRSBs were used with aggregate horizontal stiffness of 94,770 kN/m. These were manufactured according to the Republic of Armenia Standard HST 261-2007 with the following sizes and physical/mechanical parameters (FIG. 14):

Proposed Structural Solution of Retrofitting by Base Isolation the Existing Building of Hematology Centre

The seismic isolation system is constructed at the basement floor level, between marks -0.9 and -1.1. The seismic isolators are placed under all columns of the superstructure, grouped in two or three seismic isolators. They are placed also within the limits of

shear walls. The given structural solution developed for cutting the columns and shear walls and placing the seismic isolators is proposed for the first time ever and it is performed in 11 stages for the columns (FIG. 15), and 12 stages for shear walls (FIG. 16).



External diameter of the bearing (D): (380 ± 2.0) mm;
 Internal diameter of the bearing's central hole (d_1): (19 ± 1.0) mm;
 Height of the bearing (H): (202.5 ± 2.5) mm;
 Thickness of the rubber layers (S): (9 ± 0.1) mm;
 Diameter of the steel shim plates (d_2): (360 ± 0.5) mm;
 Thickness of the steel shim plates (S_1): (2.5 ± 0.1) mm;
 Diameter of the upper and lower flanges (d_3): (376 ± 0.5) mm;
 Thickness of the upper and lower flanges (S_2): (20 ± 0.2) mm;
 Thickness of this flanges' protective layer (S_3): (2 ± 0.1) mm;
 Mass of the bearing: (77.5 ± 2.5) kg;
 The bearing must withstand a maximum (design) permissible vertical loading of 1500 kN;
 Shear modulus of the bearing's rubber must be (0.97 ± 0.15) MPa;
 Vertical stiffness of the bearing: no less than 300 kN/mm;
 Horizontal stiffness of the bearing: (0.81 ± 0.1) mm;
 The bearing must withstand a maximum (design) permissible horizontal displacement of 280 mm, without causing cracks greater than 3 mm deep and 6 cm long;
 Shore A hardness of the bearing: 70 ± 5 points;
 Damping coefficient of the bearing: 13-15%.

FIG. 14. DIMENSIONS AND PHYSICAL/MECHANICAL
PARAMETERS OF THE SEISMIC ISOLATION LAMINATED
RUBBER-STEEL BEARING

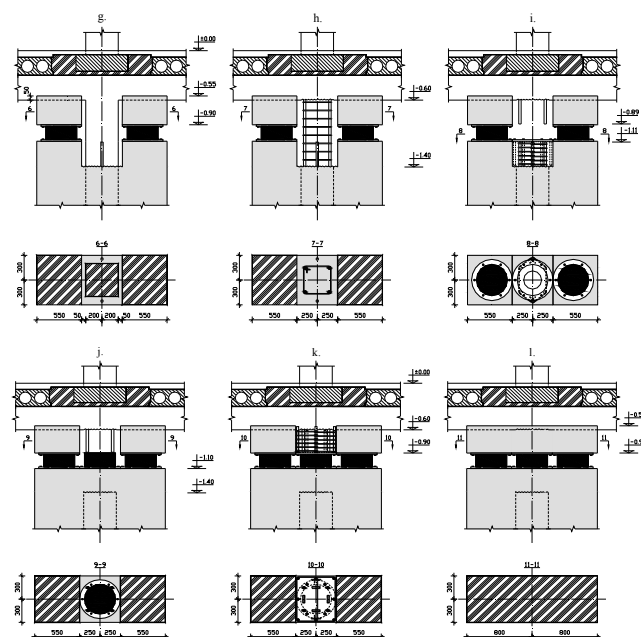
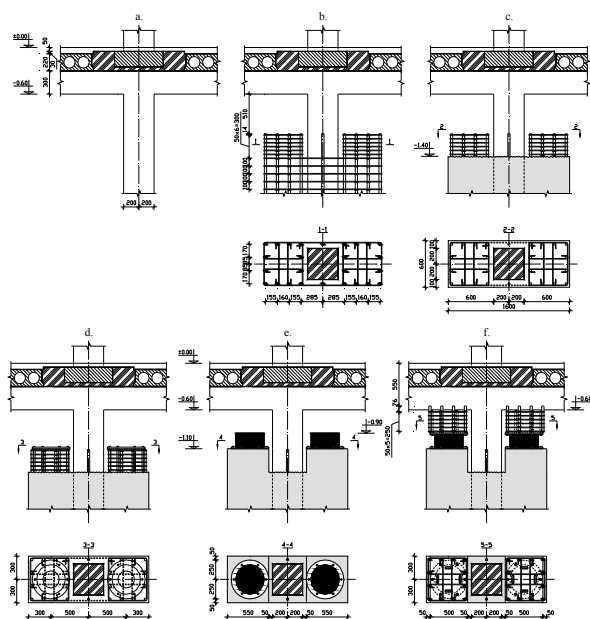
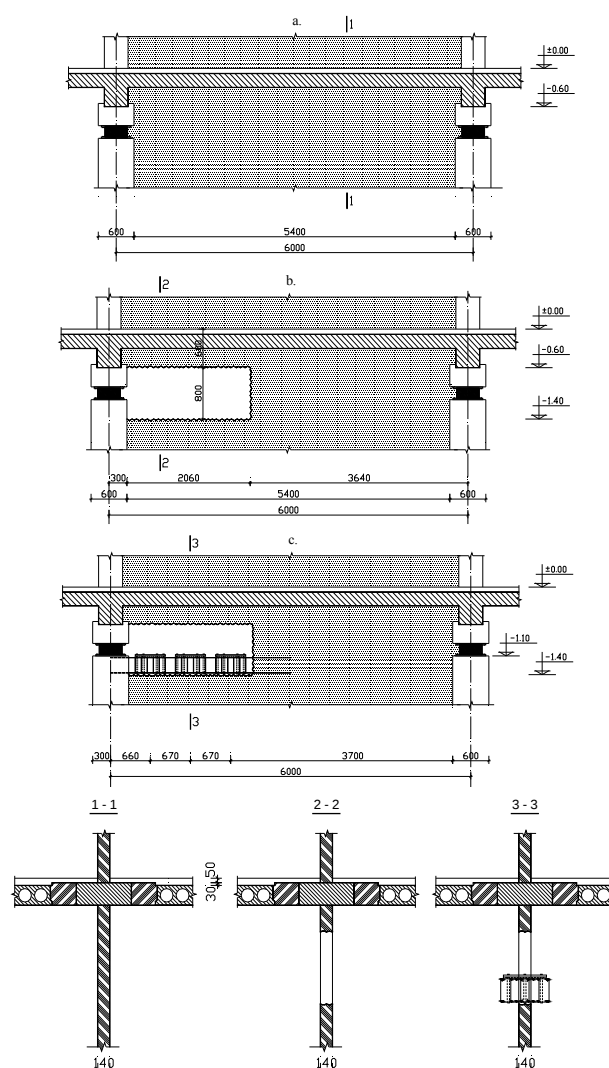


FIG. 15. STAGES OF INSTALLATION OF THE SEISMIC ISOLATION RUBBER BEARINGS UNDER THE INTERIOR COLUMNS OF THE HEMATOLOGY CENTRE EXISTING BUILDING



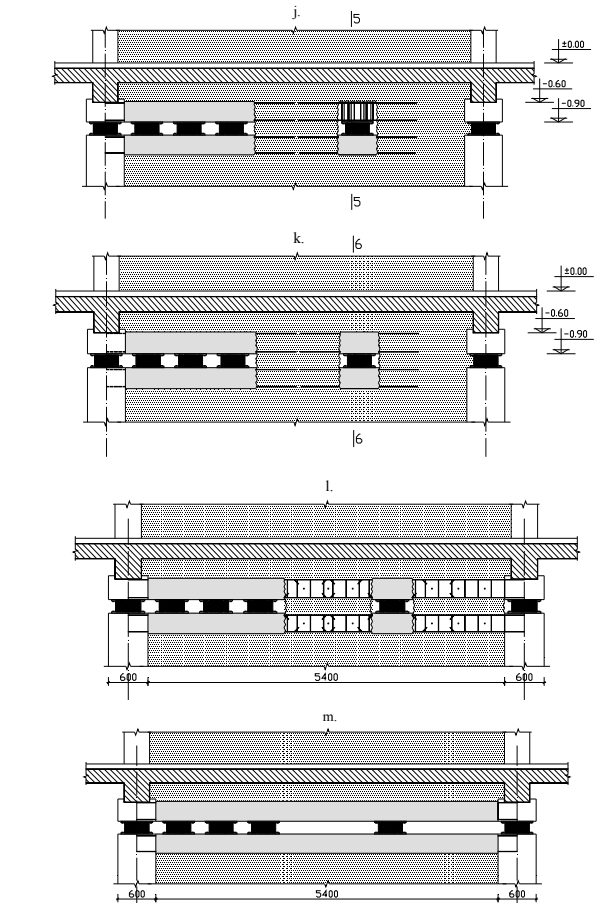
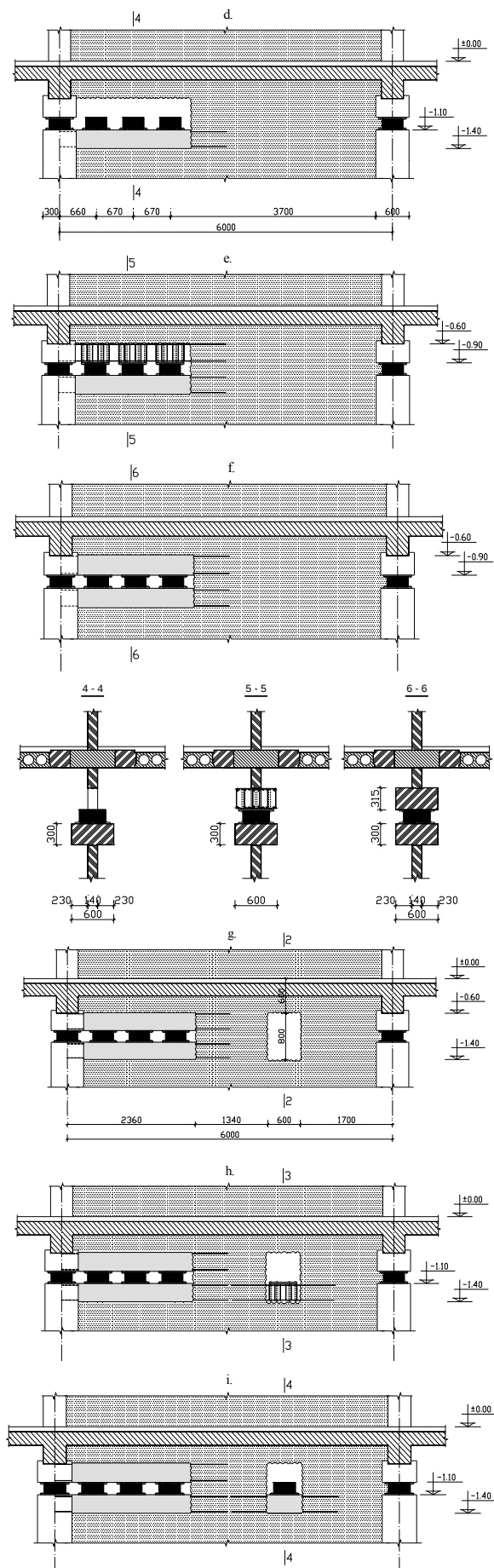


FIG. 16. STAGES OF INSTALLATION OF THE SEISMIC ISOLATION RUBBER BEARINGS WITHIN THE LIMITS OF THE SHEAR WALLS OF THE HEMATOLOGY CENTRE EXISTING BUILDING

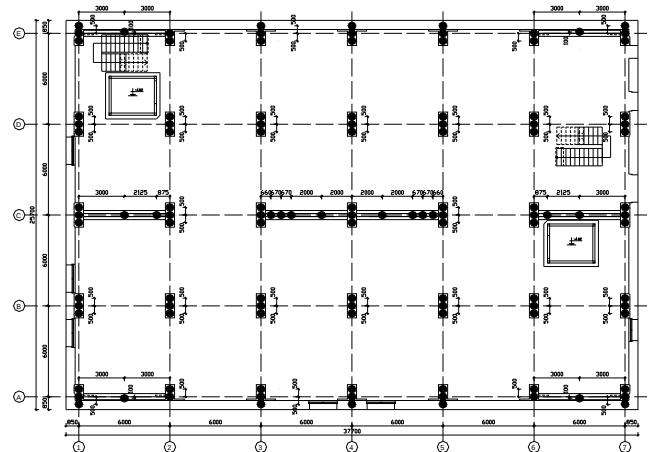


FIG. 17. PLAN OF LOCATION OF SEISMIC ISOLATORS ON THE LEVEL OF THE BASEMENT OF HEMATOLOGY CENTRE EXISTING BUILDING

As concrete is casted on the parts containing additional reinforcement around basement columns, it is necessary to follow that the lower sockets of seismic isolators are in strictly horizontal position. The same applies to concreting of the lower pedestals in sheer walls of the basement. All operations related to cutting

the columns till the stage 6 can be performed simultaneously. However, after cutting a first column, all remaining stages up to stage 11 inclusive have to be performed for it, by concreting the part above the seismic isolator. Afterwards, the next column can be dealt with and so on. In parallel to the above-mentioned operations, the shear wall cutting can be performed up to the stage 5 inclusive. It is not allowed to make openings in the shear walls next to each other simultaneously. Placing all isolators of the seismic isolation system brings in separating of the building's superstructure from its base (FIG. 17). Consequently, the mass of the building and horizontal seismic loads are passed to vertical structures and footings of the basement floor only through seismic isolators.

Additional reinforcement around existing columns of the basement is anchored both to the existing spread footings and newly designed beams that connect the spread footings to each other. The mentioned additional parts increase cross-sections of the columns and ensure their required stiffness. Only after placing the reinforcement cages for these parts, concrete can be cast to make the designed mutually perpendicular strap beams that will connect the existing spread footings. Special attention needs to be paid to the stairs to be built near the building's back entrance and those leading to the basement. All these structures have gaps between them and superstructure. These gaps ensure unhindered movement of the superstructure and displacement of the seismic isolation system during design earthquakes. In the basement floor limits, the elevator shafts have metallic carcasses, which are hung on new beams designed at the mark ± 0.00 . There are 100 mm gaps between the lower parts of the mentioned metallic shafts and bottoms of the elevator pits. The sizes of pits are chosen in such way that during design earthquakes they allow free movement of elevator shafts, without touching the pit walls.

The seismic isolation works around the perimeter of the building are performed in a specific sequence. First, earthworks are implemented. According to the design, trenches are dug along the outer perimeter of the building. Then, the self-supporting walls at the first floor level and part of the walls encasing the basement down to the mark -1.10 are dismantled, and all façade beams along the outer perimeter of the building are constructed. Afterwards, around the basement's outer perimeter retaining walls are built, which are covered by cantilever slabs, in order to protect the formed gap from precipitation and avoid possible accumulation of

trash. However, the main purpose of this gap is to ensure effective action of the seismic isolation system during a seismic impact.

Once the seismic isolation system is completed, all partitions of the basement have to be built, with gaps ensuring unhindered movement of bearing structures above and below the seismic isolation plane relative to each other. The sizes of the gaps are determined by displacement values obtained by calculations. The design involves constructing 50 mm thick R/C layers on all inter-storey floor slabs of the building. For this purpose, top surfaces of all prefab floor slabs and connecting cross-beams have to be bared, whereas the joints between these structural elements have to be cleaned from debris. Before making the R/C layers, all surfaces and joints must be thoroughly washed. After that, 300 mm long rebars with diameter of 8 mm have to be placed in joints with a spacing of 900 mm and concrete has to be cast. The rebars are necessary for creating reliable connection between reinforcement meshes of R/C layers and existing prefab slabs. Given the extremely low quality of connection between existing shear walls and columns, it is also planned to strengthen these joints with R/C coatings. The areas to be coated must be cleaned beforehand from plaster and washed.

Analysis of the Seismic Isolated Existing Building of Hematology Centre on the Basis of the Armenian Building Code and Acceleration Time Histories

According to a geological report, the site of the building is located in the Seismic Zone 3, and the site Soil Category is II corresponding to the Republic of Armenia Building Code (RABC II-6.02-2006). The report suggests an expected peak ground acceleration value of 0.4g.

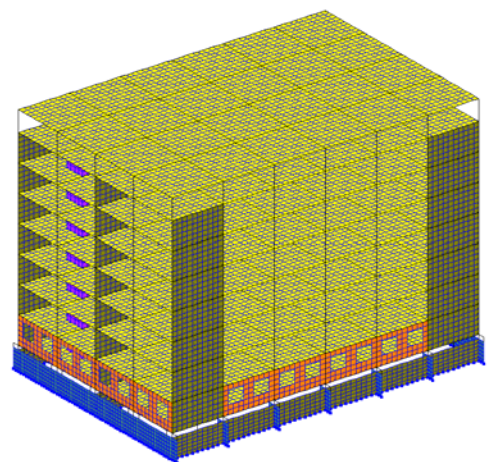


FIG. 18. THE 3D DESIGN MODEL OF THE SEISMIC ISOLATED HEMATOLOGY CENTRE EXISTING BUILDING

Vertical loading and seismic impact analysis of the seismic isolation system and the whole structure was performed in accordance with RABC II-6.02-2006 and by the acceleration time histories, using LIRA-SAPR2013 R2 software. The 3D design model (FIG. 18) was developed using bar frame finite elements, as well as membrane finite elements, with due consideration of the structural solution of the superstructure (i.e. part of the building above the seismic isolation plane).

According to the RABC II-6.02-2006, the following parameters were assumed for analysis:

- soil category II;
- soil conditions coefficient is $K_0=1.0$ and the site prevailing period of vibrations $0.3 \leq T_0 \leq 0.6$ sec;
- permissible damage coefficient for determining displacements – $K_1=0.8$;
- permissible damage coefficient for analysis of seismic isolation system and reinforced concrete structures below it – $K_{1z}=0.8$;
- permissible damage coefficient for analysis of the superstructure – $K_1=0.4$;
- importance coefficient of the building – $K_2=1.3$;
- coefficient of seismicity – $A=0.4$.

TABLE 1 ACCELERATION TIME HISTORIES SELECTED FOR EARTHQUAKE RESPONSE ANALYSIS OF THE SEISMIC ISOLATED HEMATOLOGY CENTRE EXISTING BUILDING

Earthquake and Record Component	Date	Predominant Period, sec	Duration, sec
Hollister (USA)	09.03.49	0.30	9
Eureka (USA) in horizontal NE direction	20.12.54	0.44	26
Bar (former Yugoslavia) in horizontal EW direction	15.04.79	0.55	15
Chiba (Japan) in horizontal NS direction	17.12.87	0.35	39
Spitak (Armenia) in horizontal EW direction	07.12.88	0.43	18
Spitak (Armenia) in horizontal NS direction	07.12.88	0.47	18
Loma Prieta (USA) in horizontal EW direction	17.10.89	0.34	10
Manjil (Iran) in horizontal NE direction	20.06.90	0.49	20

The following 8 acceleration time histories given in TABLE 1 were selected for calculations and acceleration amplitude was scaled to $0.52g$ ($0.4g \times 1.3$) taking into account the importance of the building. The oscillations periods obtained for the building for the first oscillation mode were equal to $T_{1\text{long}}=1.9$ sec in longitudinal and $T_{1\text{trans}}=2.0$ sec in transverse directions.

Maximum design displacements were equal to $D_{\text{max, long}}=146$ mm and $D_{\text{max, trans}}=126$ mm, respectively. As an example, TABLE 2 presents some results of calculations related to the middle axes of the building in mutually perpendicular directions. Shear forces impacting the seismic isolation system, horizontal displacements and accelerations of the seismic isolation system and all floors and maximum drifts of superstructure's floors, according to calculations by RABC II-6.02-2006 and respective average values by the time histories analysis are given in this TABLE 2.

TABLE 2 SOME RESULTS OBTAINED BY CALCULATIONS IN ACCORDANCE WITH ARMENIAN BUILDING CODE AND AVERAGE BY THE TIME HISTORIES FOR SEISMIC ISOLATED HEMATOLOGY CENTRE EXISTING BUILDING

Calculated Values	As per RABC II-6.02-2006		Average by the Time Histories	
	longitudinal direction along middle axis "C"	transverse direction along middle axis "4"	longitudinal direction along middle axis "C"	transverse direction along middle axis "4"
$S_{i.s.}$, kN	13050	12100	11200	9900
$D_{i.s.}$, mm	119.9	122.6	109.1	105.5
$A_{i.s.}$ in portion of "g"	0.137	0.119	0.125	0.103
D_n , mm A_n in portion of "g"	1	121.0/0.138	128.5/0.125	110.0/0.126
	2	123.5/0.142	137.9/0.134	112.4/0.129
	3	125.8/0.144	147.7/0.144	114.5/0.131
	4	128.2/0.146	157.3/0.153	116.6/0.133
	5	130.6/0.150	166.7/0.162	118.8/0.136
	6	133.0/0.152	175.4/0.171	121.0/0.138
	7	135.5/0.155	183.1/0.178	123.2/0.141
	8	137.4/0.157	185.6/0.181	125.0/0.143
Δ , mm	2.5	9.8	2.4	8.4

$S_{i.s.}$ – Shear forces at the level of the seismic isolation system

$D_{i.s.}$ – Displacements of the seismic isolation system

$A_{i.s.}$ – Accelerations above the seismic isolation system

D_n – Displacements of the n^{th} floor of superstructure

A_n – Accelerations of the n^{th} floor of superstructure

Δ – Maximum drifts of the floors of superstructure

The obtained results prove high effectiveness of the seismic isolation system, thanks to which the superstructure of the Hematology Center building practically will not deform during an earthquake and will act as a rigid body. This will ensure high reliability of the building, which will suffer no damage under seismic impacts, since the structural elements below and above the seismic isolation plane will work only in the elastic phase. Indeed, according to the RABC II-6.02-2006, the permissible drift in longitudinal direction (for braced frames) is equal to $1/300$ of the floor height, which comprises 8.3 mm for the technical floor and 11.0 mm for the other floors. These values are about 4.5 times in average bigger than the calculated drifts. Also in transverse direction (for moment resisting frames) permissible drift is

equal to 1/200 of the floor height, which comprises 12.5 mm for the technical floor and 16.5 mm for the other floors and these values are about 1.8 times in average bigger than the calculated drifts. An input acceleration of 0.52g at the foundation bed gets damped in average up to 3.3 times in the superstructure, and accelerations induced at the first and last floor slabs of the structure differ only by around 28% in average.

The obtained results also show that vertical loads on seismic isolators do not exceed the stipulated value of 1500 kN, which is achieved through satisfying the requirements set in paragraphs 10.5.4 and 10.5.7 of the RABC II-6.02-2006. Consequently, there is practically no eccentricity between the horizontal stiffness center of the seismic isolation system and projection of the structure's mass center on SILRSBs' plane. This is proven and also can be well observed in analysis by the time histories during the oscillations of the building.

Conclusions

Paper briefly describes seismic isolation technologies developed by the author for retrofitting of the different types of existing buildings. Four projects, where base isolation is applied, are mentioned, demonstrating retrofitting experience accumulated in Armenia.

Details of the new and original structural concept for retrofitting of the existing 8-story R/C frame hospital building are presented in the paper. This is the most recent application in the city of Yerevan and the retrofitting process is currently going on in the mentioned building. Stages of installation of the seismic isolation rubber bearings under the columns and within the limits of the shear walls in the basement of this building are described.

Results of analysis of this building by the Armenian Seismic Code and the time histories have shown that the structural elements below and above the seismic isolation plane will work only in the elastic phase. The permissible floor drifts are about 2-4 times bigger than the calculated values. An input acceleration of 0.52g at the foundation bed gets damped in average up to 3.3 times in the superstructure.

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Mikayel G. Melkumyan was born on June 10, 1951. He started his scientific and practical activity in 1973, immediately after graduation from the Civil Engineering Department of Yerevan Polytechnic Institute, carrying out both design works and experimental-theoretical research to study the behavior of various reinforced concrete structures

under seismic actions. In 1983 he defended his thesis for the degree of Candidate of Engineering Sciences and began to lead the Department of Earthquake Resistant Construction at the Armenian Scientific-Research Institute of Construction and Architecture. After the Spitak earthquake of December 7, 1988 in Armenia, Prof. Dr. Melkumyan dedicated himself to the deep analysis of consequences of this and other earthquakes and reasons for widespread destructions of various buildings and structures.

From April 1990 through March 1991 he conducted research at the Institute of Industrial Science (IIS), University of Tokyo, where he was invited by Prof. Tsuneo Okada, Director of the Institute. On the basis of his experimental research works he created a new hysteresis model to describe the shear behavior of reinforced concrete structures (walls, diaphragms). As it is indicated in the Certificate granted to him by the IIS, this model and the formula proposed by him for calculation of horizontal stiffness of diaphragms were accepted in Okada and Nakano laboratory, and the model was incorporated in the computational software for earthquake response analysis of multistory frame buildings with predominance of shear deformation. It is also mentioned in the Certificate that this research work will have a considerable contribution to earthquake resistant construction and earthquake damage mitigation in the world.

After his return from Japan, from 1992 through 1996 he was a teaching Professor at the College of Engineering of the American University of Armenia, giving lectures on non-linear behavior of reinforced concrete structures and design principles thereof in earthquake resistant construction. At the same time he led the Earthquake Engineering Center of the National Survey for Seismic Protection under the Government of Armenia. From 1993 through 1997, having been approved by the Government for the position of Director, he managed the Spitak Earthquake Zone Reconstruction Project, financed by the World Bank. From 1993 he started his work on development and application of seismic isolation systems for buildings and structures in Armenia, in the meanwhile defending his thesis for the degree of Doctor of Engineering Sciences in 1997 on the subject "Formation of the Dynamic Design Models for Seismic Response Analysis of Reinforced Concrete Buildings and their New Structural Solutions".

During a short period of time in 1995-1996, devoting himself to the challenge of increasing earthquake resistance of existing buildings, he developed two unique methods of protecting existing buildings from earthquakes through base isolation and isolated upper floor without interrupting exploitation of the buildings. His new technologies were successfully implemented in Armenia, where for the first time in the world a 5-story stone apartment building and over 60 years old 3-story stone school building, which had a historical and architectural value, were retrofitted by base isolation without evacuation of inhabitants and interruption of school functioning. Besides, for the first time seismic

resistance of two existing 9-story apartment buildings of standard frame-panel design was enhanced by application of the isolated upper floor. These works are unprecedented in the world practice of earthquake resistant construction of the time.

Later on, his technology for seismic isolation of existing stone buildings (Patent of the Republic of Armenia № 579) was successfully applied in Russia during retrofitting by base isolation of a 100 years old bank building in Irkutsk city. Afterwards, the Government of Romania ordered a design for retrofitting about 180 years old municipality building in Iasi city, which he accomplished using the same technology.

His works in the fields of both non-linear behavior of reinforced-concrete structures and seismic isolation are well known to the international professional community by the weighty contribution to the science and practice of earthquake resistant construction. He has authored and co-authored 195 scientific works, including 15 books, 10 normative documents, and 12 inventions. Among them three monographs: *Formation of the Dynamic Design Models for Seismic Response Analysis of Reinforced Concrete Buildings and their New Structural Solutions*. Yerevan, 1993; *New Solutions in Seismic Isolation*. Yerevan, LUSABATS, 2011; *Non-Linear Behavior of Reinforced Concrete Structures under Seismic Actions*. Yerevan, LUSABATS, 2013. More

than 120 of his scientific works have been published in international journals and proceedings of the World, European, and National Conferences in 29 countries of the world. As a principal structural engineer or member of the designers' groups he has designed 89 earthquake resistant residential, civil, and industrial buildings.

He is the President of the Armenian Association for Earthquake Engineering, the Vice-President of the International Association of CIS countries on Seismic Isolation, a Honorary Member of the Anti-Seismic Systems International Society (ASSISi), a Member of the Saint-Petersburg Arctic Academy of Sciences, a Corresponding Member of Engineering Academy of Armenia, an International Expert in Seismic Protection of Buildings and Structures of the Professional League of Experts of the CIS countries' Commission on Earthquake Resistant Construction and Disaster Reduction, an overseas Member of the Research Center of Earthquake Resistant Structures of the IIS, University of Tokyo, a Member of the European Association for Structural Dynamics and European Association for the Control of Structures, a Member of the Editorial Board of International Journal on Civil Engineering & Urban Planning (IJCEUP) of the Wireilla Scientific Publications, the Founder of the "Save the Yerevan Schools from Earthquakes" Foundation.